Int. J. on Recent Trends in Engineering and Technology, Vol. 9, No. 1, July 2013

Development Of Online Sensor For CO_2 Measurement In Exhaled Air & Signature Analysis For Asthma & COPD — An Attempt

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***Abstract—* This method is used for the online measurement of carbon dioxide in the exhaled air. The transit time for the ultrasonic waves to travel from the transmitter to the receiver, located at the two ends of the Kundt's tube, is a function of the density of the medium present in the tube. The variation in the CO_2 concentration in various patients causes change in the density of the medium, ultimately causing the change in the transit time of ultrasonic waves in the tube. Thus, the different transit times help in giving various concentrations of carbon dioxide in exhaled air.**

***Index Terms:* Online sensor, CO_2 measurement, ultrasonic waves, signature analysis, asthma, COPD.**

I. Introduction

The literature survey of the whole experimentation was extensively carried out.

A. Importance of CO_2 Measurement

The measurement of CO_2 is very important for diagnosis of any disease in the human body. Firstly, the proportion of CO_2 increases enormously from 0.04% in the inhaled air (N_2:78%; O_2:21%; Ar:1% ; CO_2:0.04%) of human being to about 4% in the exhaled air (N_2:78%; O_2:21%; Ar:1% ; CO_2:4%). Secondly, CO_2, a gas by-product produced by human cellular metabolism and finally exhaled out can be measured to reflect the function of metabolism, circulation and ventilation. It is considered as the sixth vital sign in evaluating the patient's medical status (the first five being blood pressure, heart rate, temperature, pain). Not only that, CO_2 (molecular weight = 44), quite a heavy gas, largely varies with the occurrence of some respiratory diseases like COPD and Asthma.

B. COPD (Chronic Obstructive Pulmonary Disease)

COPD is a group of diseases that includes chronic bronchitis and emphysema. The common characteristic of these diseases is obstruction to airflow out of the lungs. Other symptoms are shortness of breath (dyspnea), chronic cough, mucus production with cough, and/or wheeze. COPD, unlike many diseases, is easily preventable. Emphysema is a disease in which cigarette smoke causes an overproduction of the enzyme elastase, one of the immune system's infection-fighting biochemicals. This results in irreversible destruction of a protein in the lung called elastin which is important for maintaining the structure of the walls of the alveoli. As the walls of the alveoli rupture, the number of alveoli is reduced and many of those remaining are enlarged, making the lungs of the patient with emphysema less elastic and overinflated. Due to the higher pressure inside the chest that must be developed to force air out of the less elastic lungs, the bronchioles, small air tubes of the respiratory system, tend to collapse during exhalation. Stale air gets trapped in the air sacs and fresh air cannot be brought in.

In chronic bronchitis, chronic inflammation caused by cigarette smoking results in a narrowing of the openings in the bronchi, the large air tubes of the respiratory system, and interferes with the flow of air. Inflammation also causes the glands that line the bronchi to produce excessive amounts of mucus, further narrowing the airways and blocking airflow. The result is often a chronic cough that produces sputum (mainly mucus) and shortness of breath. In COPD, respiratory function is impaired by obstruction to normal air flow, reducing exchange of oxygen and carbon dioxide. There is air trapping and over-inflation of parts of the lungs. Later, the affected person develops dyspnea as a result of difficulty in exhaling air through the obstructed air passages.

C. Asthma

Asthma is a common chronic inflammatory disease of the airways characterized by variable and recurring symptoms, reversible airflow obstruction, and broncho-spasm. Symptoms include wheezing, coughing, chest tightness, and shortness of breath. People who have asthma have inflamed airways. This makes the airways swollen and very sensitive. They tend to react strongly to certain substances that are breathed in. When the airways react, the muscles around them tighten. This causes the airways to narrow, and less air flows to your lungs. The swelling also can worsen, making the airways even narrower. Cells in the airways may make more mucus than normal. Mucus is a sticky, thick liquid that can further narrow your airways. Asthma affects people of all ages, but it most often starts in childhood. A combination of factors (family genes and certain environmental exposures) interacts to cause asthma to develop, most often early in life. These factors include:

- An inherited tendency to develop allergies, called atopy
- Parents who have asthma
- Certain respiratory infections during childhood
- Contact with some airborne allergens or exposure to some viral infections in infancy or in early childhood when the immune system is developing

DOI: 01.IJRTET.9.1.39

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D. CO_2 measurement techniques

There are many offline and online techniques for CO_2 measurement.

Offline techniques are as follows:

(1)FTIR spectroscopy :

"Reference [10]" It is Fourier Transform Infrared spectrometer "Fig. 1". The chemical bonds in the substance to be measured absorb a specific wavelength of infrared spectrum. The radiation not absorbed (transmitted) produces an absorption spectrum and is compared to the database library. In the Fourier transform Infrared spectroscopy used for the detection and measurement of CO_2, an electronic conductance sensor is used. On this sensor, a coating of a nanomaterial called barium titanate ($BaTiO_3$) is given. It is observed that when this sensor is exposed to the CO_2, the gas is adsorbed on the $BaTiO_3$ layer. This changes the surface properties of the coating ultimately changing the conductivity of the sensor. This raw data obtained from the conductance variation is processed by using the Fourier transforms and a spectrum is obtained, thus giving the value of the amount of CO_2 in the exhaled air.

Figure 1: FTIR spectrometer

(2)Ion mobility Spectroscopy :

"Reference [11]" Ion mobility spectrometry (IMS) "Fig. 2" is an analytical technique used to separate and identify ionized molecules in the gas phase based on their ion mobility in a carrier buffer gas. Once the chemical is a charged particle, it can be moved by placing a similar charge near it to push it or an opposite charge to attract it. In the case of IMS, the ionized particle is introduced into a drift tube and the opposite charge is electronically introduced on the other end of the tube at the detector. Due to attraction, the particle moves down the drift tube to the opposite end. Using temperature and drift gas, the particle will move through the tube at a very reproducible rate. The amount of time it takes to reach the end of the tube is called the drift time. This time can be compared to previously recorded drift times of chemicals of concern. If the time of the particle is within the established drift time window, the software reports the particle as the chemical of concern. IMS can detect multiple chemicals because the particle size is directly comparable to the amount of time it takes to "drift" to the end of the tube. The larger the particle, the longer it takes to make it to the other end for detection. Separation and drift time comparison makes this instrument a simple and powerful tool and can be used for CO_2 detection.

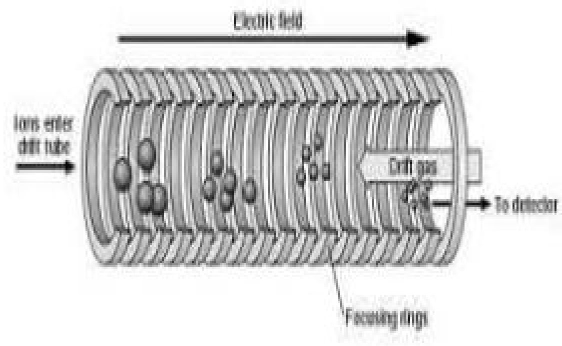

Figure 2: Ion mobility spectroscopy (IMS)

(3) CO_2 microsensor based on tin oxide doped with copper oxide:

"Reference [8]" "In this method, a CO_2 microsensor based on nanocrystalline tin oxide (SnO_2) doped with copper oxide(CuO) is used. The combination of this technique is coated on a resistive film sensor. These nanosensors are fabricated with the means of microelectromechanical systems (MEMS) technology and sol-gel nanomaterial-synthesis processes. The doping level of SnO_2:CuO=1:8(molar ratio). When the ratio is in this proportion, there is a linear response to CO_2 concentrations for the range of 1 to 4 % CO_2 in air at 450p C.

Online Detection Methods :

(1)NDIR technology :

"Reference [3]" The method for concentration detection of CO_2 gas is based upon the NDIR measuring technique and Lambert-Beer's equation. The equation is given as follow:

$I = I_0 * e^{(-kcl)}$, where,

I_0 = the intensity of light incident on the sample;

I = the measured intensity of light after the sample;

k = the absorption coefficient of the analyte gas at the characteristic wavelength (cm^2);

c = the concentration of the analyte gas($1/cm^3$);

l = the pathlength or the distance that the light that passes through the sample gas(cm).

Components:

A pulsed infrared (IR) light source: Excitation frequency is about 1Hz to provide a non-dispersive infra-red flashing source. An airway chamber: having l path length with a gas inlet and a gas outlet at the up side edge as shows. The gas inlet is connected to our nose with a nose-oxygen-tube like pipe, while the gas outlet gives a way for CO_2 gas flowing out of the chamber, and the chamber will be full of CO_2 gas when performing detection An IR detector: It is a dual channel thermopile sensor housing with two window openings (channel T1 and T2) Channel T1: carries a band-pass wavelength centered at 4.0 µm, other than CO_2 gas absorption band at 4.26 µm, acting as reference. Channel T2: senses light at a specific wavelength of 4.26 µm, a predominant absorption band of CO_2 gas "Fig. 3".

Thus except ground signal, three other signals that the

DOI: 01.IJRTET.9.1.39

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thermopile detector gives are a reference signal for reference use, a real measured signal, and a temperature signal giving the real temperature inside the thermopile sensor for later temperature compensation use. Basically, these millivolts (mV) level signals should be amplified, conditioned via a detection module, and then the actual CO_2 concentration can be calculated according to the Lambert-Beer's equation by the microcontroller in an instrument module.

Advantages :

1. Range of measurement : 0-3000 ppm
2. Accuracy : +/- 5%

Disadvantages :

False reading by precipitation of moisture on optical elements.

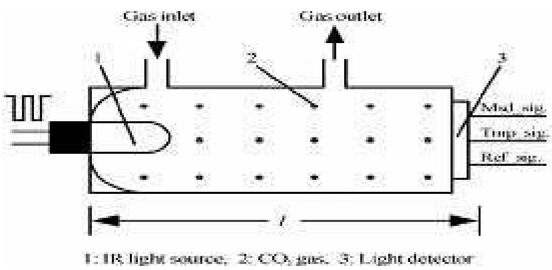

Figure 3:NDIR assembly

(2) Capacitive CO_2 sensor with on-chip heating :

"Reference [9]" In this a CO_2 sensor based on thin film interdigital capacitor with an integrated heater on a quartz substrate [5]. An organically modified silicate is used as the sensitive film on it.

Principle:

Exposure to CO_2 changes the dielectric properties of the substrate, which in turn changes the capacitance of the sensor.

Design:

Thin-film metal resistor acts as the heating element and is designed for a temperature range between 30p C and 100p C. The optimal shape of the resistor with respect to a good temperature uniformity across the IDC area was obtained by finite-element analysis (FEA) simulations. Quartz glass was chosen as the substrate material because of its low dielectric constant, ,=3.9, and low thermal conductivity, 1.5 W m-' K-' The sensitive layer consists of 3-amino-propyl-trimethoxysilane(AMO) and propyl-trimethoxysilane(PTMS). PTMS was incorporated to reduce the cross-sensitivity to H,O. The sensitive layer was deposited by a spin coating process followed by a sol-gel transition to form a solid film. The adsorption mechanism is based on a reversible interaction between CO_2, and residual water. An evaluation of the losses through radiation showed that this type of heat transfer can be neglected in the temperature range below 100p C "Fig. 4". The heating resistor and the temperature-measuring resistors are arranged around the IDC structure. The sensor was fabricated by using standard thin film technology.

Advantages:

1.Operating temperature: 70p C.

2.Heating power of 210mW is required.

3.Response of the directly heated sensor is the same as the response of a sensor that is thermostatted in a temperature chamber.

4.No effect of change in ambient temperature.

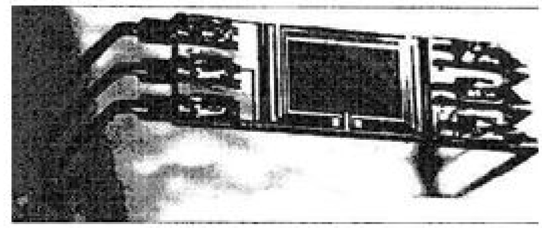

Figure 4: Capacitive CO_2 sensor

(3) Mass sensitive detection of CO_2 by amino group functionalized polymer:

"Reference [7]" The CO_2 sensor has a sensitive coating of amino group functionalized polymer, by using quartz microbalance transducer [1]. Various sensitive materials have been developed for CO_2 sensors which are based upon amino groups in monomers or polymers and which are utilized as coatings in mass sensitive and capacitive transducers at low temperatures. The sensor responses of the monomeric amine-coated sensors were reversible and reproducible, but small and hence the sensors can only be used to detect rather high concentrations of CO_2 (2 %). The TABLE I and TABLE II give the details of the various polymers and used for different ranges of CO_2 detection.

TABLE I. PROPERTIES OF AMINO GROUP FUNCTIONALIZED POLYMER USED FOR CO2 DETECTION 1

POLYMER	DETECTION LIMIT	PARTIAL SENSITIVITY
PPI	< 200	18.3
PEI	<100	77.8
APDMS	< 1000	0.41
PAPPS	< 200	7.54
PAPPS	< 50	21.0
PAPOS	< 200	50.4

Advantages :

1.Operating temperature : 30p C to 0p C

2. Detection range: 50 to 200ppm

3.Good sensitivity and selectivity at high level of reversibility and reproducibility for the continuous monitoring of CO_2.

4.Low cost and easy handling.

5.Fast response

4) Acoustic Sensor:

Principle :

"Reference [6]" Here the sensor makes use of an electro-acoustic element coupled to a Kundt resonator. The Kundt resonator is a simple resonating tube. Standing waves are

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TABLE II. PROPERTIES OF AMINO GROUP FUNCTIONALIZED POLYMER USED FOR CO2 DETECTION 2

POLYMER	OPERATING TEMPERATURE (DEGREE)	MINIMUM LIFE TIME (WEEKS)
PPI	25	1
PPI	30	2
PPI	60	3
PPI	70	12

formed in them. The resonance frequency (f) of these standing waves is determined by the mean molecular mass of the gas in the tube. Variations in the CO_2 concentration cause changes in the mean molecular mass of the gas which ultimately changes the resonance frequency. Thus we can determine the concentration of the gas by using the following equation :

$(\Delta f/f) = (-(MCO_2-MO)*XCO_2)/(2MO)$, where, f: Resonant frequency

MCO_2 : molecular mass of CO_2 MO : average molecular mass of gas XCO_2 : CO_2 concentration

"Fig. 5" The setup consists of an ultrasonic transmitter, operating at 40kHz coupled to an acoustic resonator according to Kundt. It is basically a piece of tubing with a length corresponding to $n*(\lambda/2)$, λ being the wavelength (λ =8.5mm at 40kHz) and 'n' is an integer.

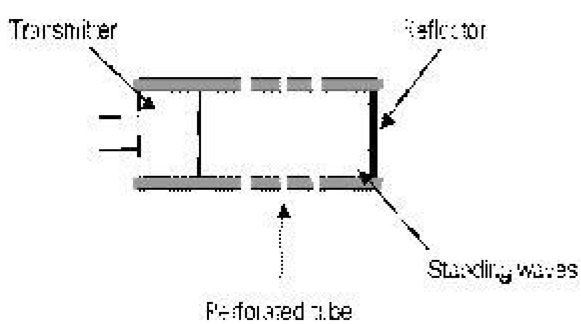

Figure 5:Acoustic CO_2 sensor

The "Fig. 6" figure shows the electrical impedance of the sensor as a function of frequency. The most prominent peak at 40.8 kHz represents the equivalent parallel resonance, whereas the peak at 39 kHz is a result of standing waves within the resonator, and is also (approximately) coincident with an impedance minimum of the transmitter itself. The 39 kHz peak will shift towards lower frequency, with increasing CO_2 concentration. The frequency shift observed is used for controlling the output frequency of an oscillating circuit. The circuit must be capable of locking at the 39 kHz peak, without locking at loops (PLL), consisting of a voltage controlled oscillator (VCO), a phase comparator and a low pass filter. The phase difference between the input and the VCO signals is driven to a nearly constant value by continuous adjustments of the VCO frequency.

Advantages:

1.Favorable resolution.

2.Compact size.

3.Low response time.

4.Low cost and non-selective.

The important disadvantage of this technique is that the average molecular mass and the composition of the gas should be known before calculating the amount of CO_2. However, fortunately, in our case, our gas is the exhaled air, whose molecular mass and composition is known to us. So this is advantageous in our situation. If the prototype dimensions are scaled down, then the operating frequency would linearly increase. The TABLE III gives the comparison of the various online techniques [4] for CO_2 measurement [2] and shows that on the various factors compared, the acoustic sensor method is more feasible and with lesser disadvantages.

II. INTRODUCTION OF THE TECHNIQUE

This principle of "The electro-acoustic sensor in Kundt's resonator" was modified and used in this above mentioned technique. In the former principle, the transmitter and receiver were placed on the same side of the Kundt's tube. The ultrasonic waves would pass along the length of the tube and get reflected from the other end of the tube due to an elastic reflector, thus causing STANDING WAVES. The length of the tube is adjusted such that, the standing waves oscillate with the resonating frequency. The change in the density of the medium in the tube caused by change in concentration of carbon dioxide causes change in the resonant frequency of the standing waves. Thus, measuring the change in resonant frequency helps in finally getting the varied CO_2 concentration. This technique was selected because of its distinct advantages- it is an online technique, its high accuracy, low response time, exhaled CO_2 range can be measured with this technique, operating temperature is the room temperature.

However, this technique was modified and the variations in the transit time for ultrasonic waves were preferred over changes in the resonating frequencies. This was done because of certain problems in its practical implementation. Firstly, the tube size mentioned in the technique was very small and carrying out experimentation on the same was not feasible. The actual experiment was carried out with known concentration of CO_2. A total of one liter of CO_2 was administered into the 14-litre chamber, which was kept at approximately 22p C and 30% relative humidity. The gas was administered 20 times and the relative CO_2 concentration was increased by 0.3% each time. The sensor was mounted inside a small tube to measure the total response time for the electronic device and the sensor. The concentration inside the tube was quickly changed from a CO_2 concentration of 3% to normal indoor air. The length of the tube was 6.7 cm and the volume 30 cm3. Thus, experimentation using such high amount of CO_2 and so small tube was not feasible. Secondly, the phased lock loop had to be implemented initially

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along with the experimentation stage. Thus this was not feasible because, the working of PLL could not be checked separately and trouble-shooting would be a problem in the case of implementation. So that principle of operation had to be slightly modified.

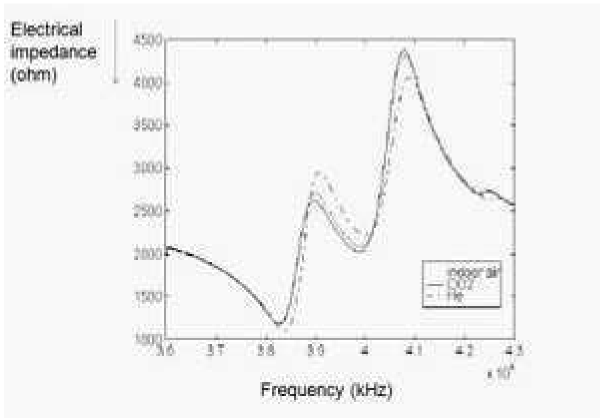

Figure 6: Electrical impedance as a function of frequency for the sensor in normal indoor air and addition of 0.007percent CO_2 and He respectively

TABLE III. COMPARISON OF VARIOUS TECHNIQUES

	NDIR	Capacitive Sensor	Aminogroup	Acoustic Sensor
Operating Temp	Room temp	70°C	25°C-60°C	Room temp
Range	0-3000 ppm	--	50-200 ppm & 500-10,000ppm	Exhaled CO_2 range
Accuracy	Low	High	Moderate	High

III. CONSTRUCTION & SETUP

A. Principle

The ultrasonic transmitter transmits ultrasonic waves which are received by the receiver. The time required by the wave to travel from the transmitter to the receiver is measured. When the CO_2 gas is introduced into the sample tube, the density of the medium for the ultrasonic waves increases, which reduces their speed thus leading to an increase in the transit time. Thus, the concentration of CO_2 can be measured as a function of the transit time.

B. Construction and Experimental Setup

In the assembly used for construction, acrylic tubes, one of length 25cm and the other of length 45cm approximately was used. Acrylic tube is used because it does not absorb the ultrasonic waves travelling in it. The inner diameter of the acrylic tube is 5cm and the outer diameter being 6cm. These are the basic dimensions of the tube. Few modifications were made in the tube as per the requirements, which are explained further.

Both the ends of the tube are closed with holes on each end, to fix the transmitter and the receiver. Small hole(s) of diameter 5 mm is made on the surface of the tube to help the sample gas in and out of the tube. These holes can vary in number from one to three.

The experimental arrangement of the same is given below: "Fig. 7"

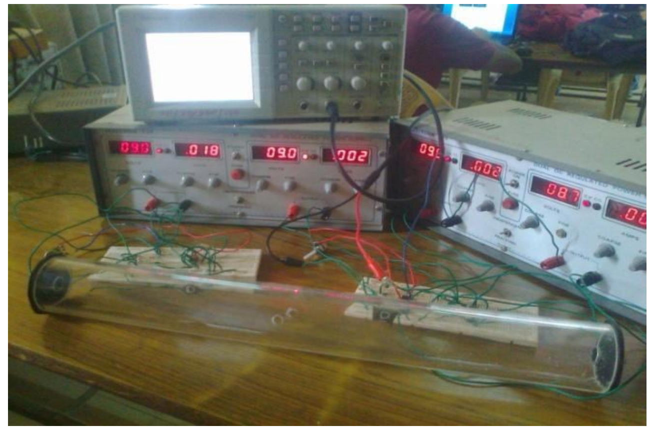

Figure 7:Experimental setup of the project

In this setup, there is a acrylic tube with the two ends closed by rubber discs with the transmitter and receiver each. This experimental setup shows the dual power supply, the DSO and the 45cm acrylic tube. As it can be seen, there are the transmitter and receiver circuits on the breadboards. The ultrasonic transmitter and receivers are placed on the opposite sides of the tube and the remaining part of the cross-section is closed by a tube. Also there are holes on the surface of the tube.

C. Transmitter circuit :

The transmitter is triggered by using the microcontroller program or by using a special triggering circuit as shown in the figure "Fig. 8".

This circuit is used to transmit ultrasonic waves through air, which are intended to be picked up by a matching ultrasonic receiver. The circuit uses a 555 timer IC configured as an astable multivibrator, i.e., it generates a continuous signal of a set frequency as long as its reset pin (pin 4) is held high. Since the ultrasonic transducer used in this circuit is one designed to vibrate optimally at about 40 kHz, the resistor and capacitor values of the circuit were chosen such that the 555 will output a signal whose frequency is about 40 kHz.

Frequency of oscillation, $F=1.45/((Ra+2Rb)*C)$

Hence to get 40 KHZ,

$Ra=1K\Omega$, $Rb=4.9K\Omega$ (A pot of 10K was used); $C=0.0033\mu F$.

This 555 output is amplified by Q1, which drives the ultrasonic transducer. The transducer then vibrates at 40 KHZ, generating ultrasonic sound waves of that frequency.

The waveform of the above circuit is given in figure below "Fig. 9":

D. Receiver Circuit :

This circuit "Fig. 10" is used to receive ultrasonic waves from the air that were transmitted by a matching ultrasonic

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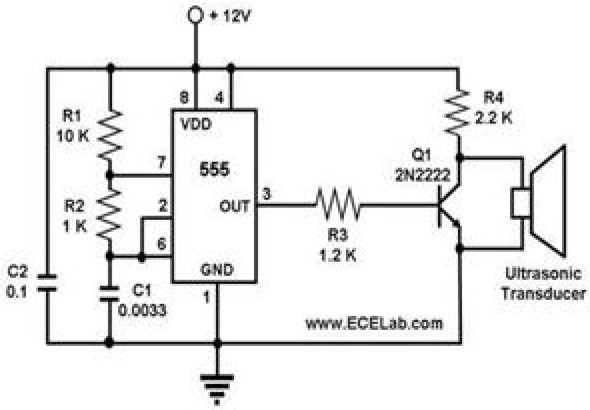

Figure 8:Schematic diagram for ultrasonic transmitter circuit

Figure 9:Waveform of 40 KHZ transmitter on DSO

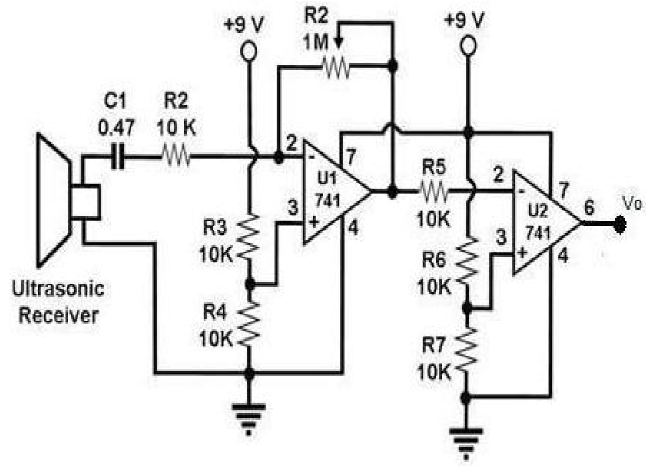

Figure 10:Schematic diagram for ultrasonic receiver circuit

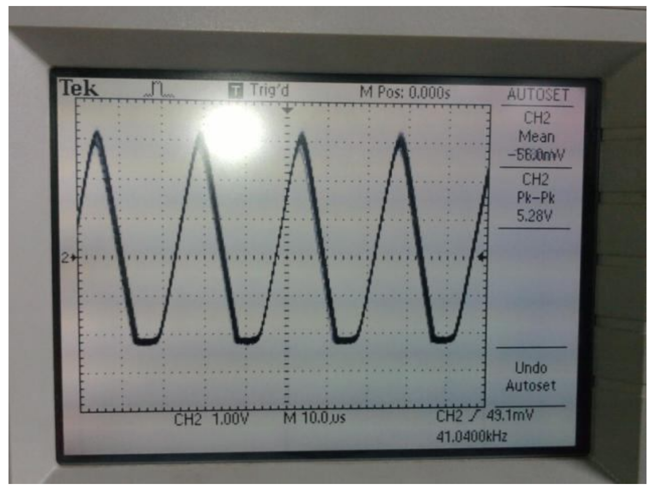

Figure 11 : Waveform of 40 KHz ultrasonic receiver after signal conditioning

transmitter located somewhere else. The ultrasonic receiver used in this circuit is one designed to vibrate optimally at about 40 kHz, When the waves from transmitter hit the receiver, the receiver vibrates and produces electric impulses, also at 40 kHz. These electric signals are amplified by the two op amps in the circuit. Op-amp 741 were used with a dual power supply, the op-amps act as comparators. Here output of voltage divider acts as a reference to the non-inverting terminal. These circuits were implemented initially on the breadboard and then it was soldered on a general purpose board. The waveform of the above circuit is given in the following diagram “Fig. 11”.

In the case of varied CO_2 concentrations, the actual time from the instant when the transmitter starts working to the instant when exactly the shown waveform is obtained is measured. In case of more CO_2 concentration, this time will be larger and vice-versa. Thus, accordingly proper results can be obtained.

It was seen that, the circuits were operating properly. However, when the transmitter and the receiver were placed next to each other, there was tremendous interference between the transmitted and the received wave. Due to that, instead of a stable wave on the DSO, three different waves were obtained. So to avoid this, the same circuits were used but the transmitter and the receiver were placed on the opposite ends of the acrylic tube and a small hole was made on the surface of the tube to insert the CO_2 gas into the tube.

IV. Experimentation

Initially, the transmitter and the receiver were placed on the same side of the tube, which could not be worked out well due to large amount of noise. So then the transmitter and receiver were placed on the opposite sides of the tube at the centre of the cross-section.

The first experimentation was carried out on a tube, 25 cm in length and having an inner diameter of 5 cm, with a hole of 0.5 cm drilled on its surface to introduce CO_2 in it. See in “Fig. 12”. Thus the volume of this tube was, V = 3.14*(radius)^2*(length) = 3.14* (2.5)^2*25 = 490.87 cm^3.

After introducing CO_2 in the tube, it was found that, the output was not efficient, because introducing CO_2 at the flowrate of 3 lpm for 7-8 sec would fill the tube After introducing CO_2 in the tube, it was found that, the output was not efficient, because introducing CO_2 at the flow rate of 3lpm for 7-8 sec would fill the tube completely and density increase in the tube was so high that the receiver couldn’t receive the transmitted wave. The receiver took almost 15-

DOI: 01.IJRTET.9.1.39

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20min to give a stable waveform of 40 kHz. This problem was overcome by using a longer tube.

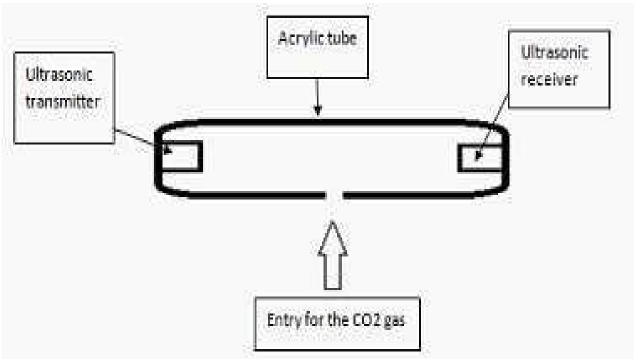

Figure 12 : Setup with 25 cm tube and one hole

The second experiment was carried out with the same conditions but with a tube of length of 45 cm. Thus, the volume of the tube came out to be 883.125 cm^3. The volume almost doubled but, as there was only one hole (i.e. the same hole functioned as an entry and exit), CO_2 gas remained in the tube for a long time affecting the output. So we introduced 3 holes for exit, out of which one was exactly opposite to the hole used for introduction of CO_2 "Fig. 13"

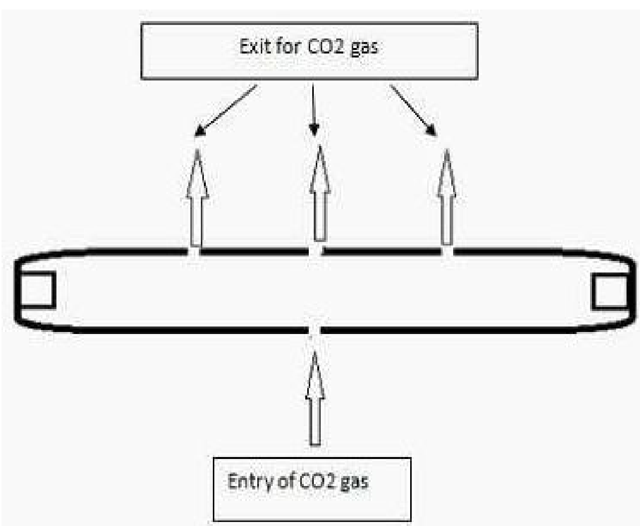

Figure 13 : Setup with 45 cm tube and 3 exit holes

Various readings like transit time, change in frequency was observed for various flowrates. At each flowrate, the gas was introduced for fixed time. Firstly, we introduced it at 4 sec for every flowrate and then for 2 sec each.

V. Observations

The experiment was carried out on different tubes and for different times.

G. Test with water vapor

Similar tests were carried out to check if there is a significant change because of water vapor. Steam was sent into the tube and change in the frequency emitted was observed. It was seen that, presence of steam had absolutely no effect on the frequency or the transit time of the ultrasonic waves being transmitted. Thus, this sensor is not at all affected by humidity or presence of moisture present in the exhaled air.

Table IV. Experiment 1 : The Co_2 Gas Was Introduced For 4 Sec & Readings For All 3 Holes Open In 45 Cm Tube

Gas flow rate (lpm)	Vol of CO_2 (cc)	CO_2 proportion in tube	Freq on gas entry (kHz)	Time (s)
2	133.33	0.1509	--	--
3	200.00	0.2264	39.9	187
4	266.67	0.3019	38.8	220
5	333.33	0.3770	33.5	250

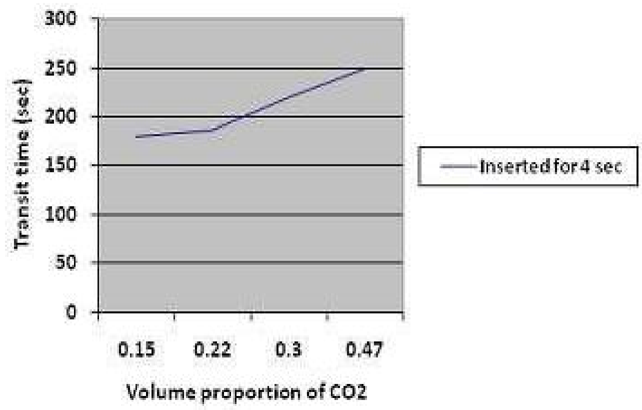

Figure 14 : Graph of transit time v/s volume proportion of CO_2 (CO_2 inserted for 2 sec)

Table V. Experiment 2 : The Co_2 Gas Was Introduced For 2 Sec & Readings For All 3 Holes Open In 45 Cm Tube

Flow rate lpm	Vol of CO_2 (cc)	CO_2 proportion in tube	Freq on gas entry (kHz)	Time (s)
2	66.67	0.0755	33.37	132
3	100.00	0.1132	34.7	192
4	133.33	0.1509	36.34	215
5	166.67	0.1887	41.00	245

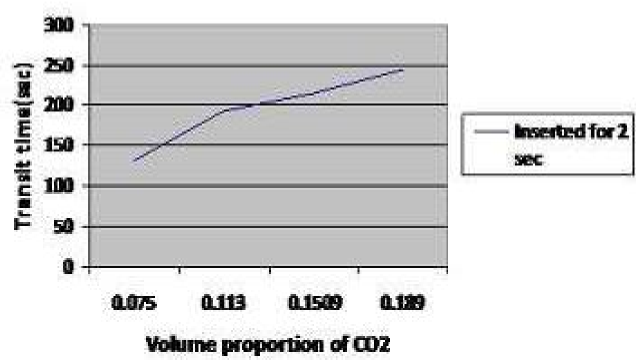

Figure 15 : Graph of transit time v/s volume proportion of CO_2 (CO_2 inserted for 2 sec)

VI. Testing And Signature Analysis

The observations obtained from the above observation tables were used as reference for the testing on different

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TABLE VI. EXPERIMENT 3 : THE CO_2 GAS WAS INTRODUCED FOR 2 SEC & READINGS WITH 1 HOLE OPEN IN 45 CM TUBE

Gas flow rate (lpm)	Vol of CO_2 (cc)	CO_2 proportion in tube	Freq on gas entry (kHz)	Time (s)
2	66.67	0.0755	39.1	151
3	100.00	0.1132	41.66	276
4	133.33	0.1509	41.42	369
5	166.67	0.1887	41	389

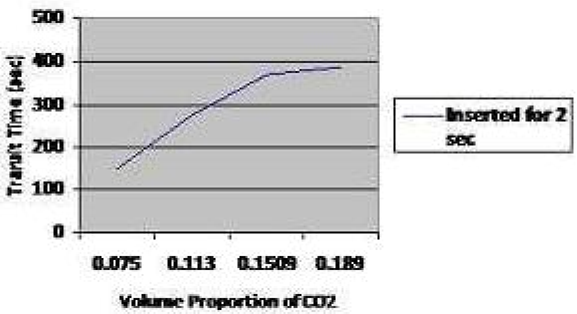

Figure 16 : Graph of transit time v/s volume of CO_2 (CO_2 inserted for 2 sec) with one hole open

TABLE VII. EXPERIMENT 4 : THE CO_2 GAS WAS INTRODUCED FOR 15 SEC & READINGS TAKEN IN 25 CM TUBE

Gas flowrate (lpm)	CO_2 volume (cc)	$V_{p\text{-}p(min)}$ (V)	Time (s)
2	500	4.64	48
3	750	4.32	60
4	1000	3.6	68
5	1250	2.36	72
6	1500	1.26	82
7	1750	0.569	95
8	2000	0.566	115
9	2250	0.5606	130

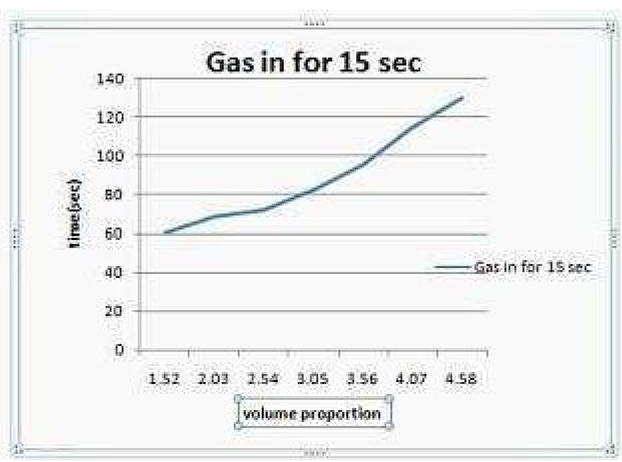

Figure 17 : Graph of transit time v/s CO_2 (CO_2 inserted for 15 sec)

subjects. In that, the sensor was tested on people with different conditions. People with different sex, age, profession and overall physique were the concerned target persons. Also people suffering with various pulmonary and respiratory diseases, especially asthma and COPD were also taken into consideration.

TABLE VIII. EXPERIMENT 5 : THE CO_2 GAS WAS INTRODUCED FOR 10 SEC & READINGS TAKEN IN 25 CM TUBE

Gas flowrate (lpm)	CO_2 volume (cc)	$V_{p\text{-}p(min)}$ (V)	Time (s)
2	333.33	--	--
3	500.00	6.16	67
4	666.67	4.86	80
5	833.33	3.84	85
6	1000.00	0.56	91
7	1166.67	0.56	100
8	1333.33	0.56	103
9	1500	0.56	105

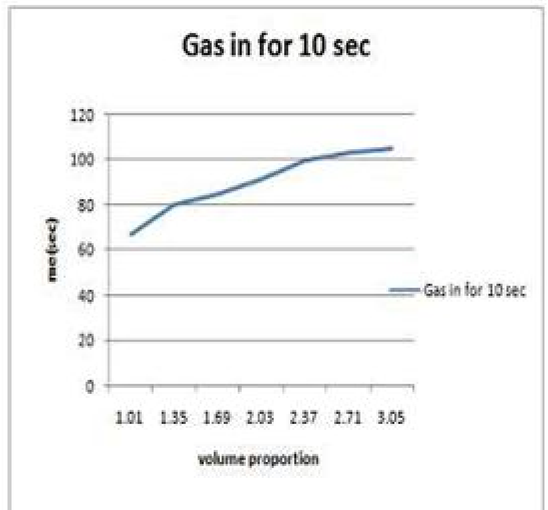

Figure 18 : Graph of transit time v/s CO_2 (CO_2 inserted for 10 sec)

TABLE IX. EXPERIMENT 6 : THE CO_2 GAS WAS INTRODUCED FOR 5 SEC & READINGS TAKEN IN 25 CM TUBE

Gas flowrate (lpm)	CO_2 volume (cc)	$V_{p\text{-}p(min)}$ (V)	Time (s)
3	250	6.96	0
4	333.33	6.8	5
5	416.67	6.64	41
6	500	5.6	46
7	583.33	4.96	70
8	666.67	4	95
9	750	3.84	105

Thus, the CO_2 concentrations of all the different people were obtained by comparing them to the standard calibrated graphs or observation tables shown above.

Then the signature analysis was also carried out. The signature analysis for asthma and COPD was intended to be carried out. It has been observed that, in the case of asthma, the CO_2 content in the exhaled air reduces initially to a great

DOI: 01.IJRTET.9.1.39

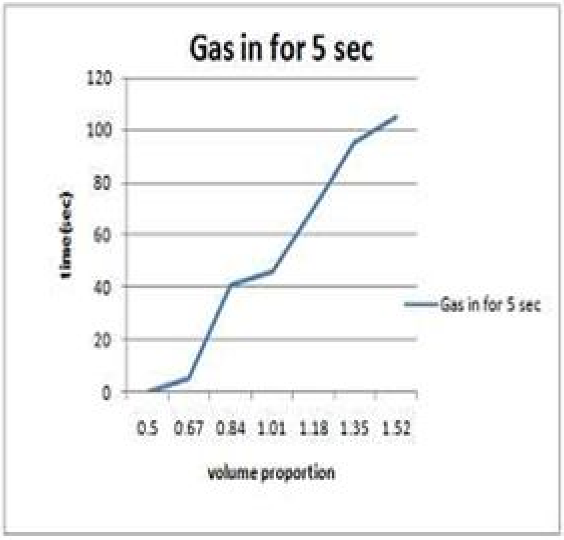

Figure 19: Graph of transit time v/s CO_2 (CO_2 inserted for 5 sec)*G*

extent (as it acts as a buffer for the abnormal condition generated), but then it increases largely in its acute stage. So high or low amounts of CO_2 cannot be a sure parameter for the diagnosis of asthma. However, in the case of COPD (cardiac obstructive pulmonary disorder), the CO_2 concentration increases largely.

Thus in the signature analysis, a particular range of CO_2 was found to be normal range. It was considered to be "NORMAL". Any reading below or above this range was labeled as "ABNORMAL" and this was the indication of possibility of the patient suffering from asthma or COPD predominantly. This was done by the use of a microcontroller.

VIII. Observations

1)In the case of experiments 4, 5 and 6, (see TABLE VII, VIII, IX), the Vp-p value taken as reference was 5.28V as shown in "Fig. 17", "Fig. 18" and "Fig. 19" and the volume of the tube was 490. 87cc. When the volume of the CO_2 gas inserted is less or almost nearby the volume of the tube, no significant change is observed in the Vp-p value, which is a good observation for the experimental analysis. In the other cases, the volume inserted is much more than the actual volume of tube.

2) In the case of experiment 6(TABLE IX) in "Fig. 19" irrespective of the CO_2 volume inserted, there is no much significant change in the Vp-p value with respect to the reference value. This shows that, the minor changes in the Vp-p value are due to the disturbance caused to the ultrasonic waves due to gas insertion.

3) In experiment 3(TABLE VI) in "Fig. 16", when only one hole is open, the time required to obtain the output wave is exactly about half as compared to the case where all the three holes are open. But in the case of all the 3 holes open, the air will get uniformly spread all over the tube rather than accumulate only at the centre.

4) Considering the experiments 2 and 3 (TABLE V, VI), in "Fig. 15" and "Fig. 16" as compared to 4 sec, when the gas is let in for 2 sec, due to low CO_2 proportion, relatively lesser time is required, but the difference is not major. This may be due to the exit hole diametrically opposite to the entry hole. Due to some air leak, the air might get escaped straightaway and easily.

IX. Inferences And Conclusion

1)Normally, the frequency of the ultrasonic waves does not change with the change in medium. But in the above experiments, the frequency changes on gas insertion because of disturbance caused and sudden change in the environment in the tube.

2) From experiments 4, 5 and 6, (see TABLE VII, VIII, IX) in "Fig. 17", "Fig. 18" & "Fig. 19", it is clear that, when the volume of the gas inserted is less than the volume of the tube, the value of Vp-p does not vary significantly. And when the inserted volume is more than the tube volume, it obstructs the wave and is amplitude and makes it very unstable. Also, later on, when there is a slight leakage, the wave starts getting back to its original value. So from this, it is clear that, Vp-p is not an important factor which can affect the CO_2 measurement reading.

3) In experiment 6 (TABLE IX) in "Fig. 19", the minor change is due to the disturbance caused to the ultrasonic wave in the tube, due to loss of homogeneity in the medium.

4) The 25 cm tube with hole open could not be successfully checked by monitoring the stabilizing of the frequency, as the settling times were disproportionately long in that case.

5) From the experiments 1, 2 and 3, (see TABLE IV, V, VI), in "Fig. 14", "Fig. 15" & "Fig. 16" on an average, the settling times to reach a stable frequency of 40 kHz are in the following order (from least to maximum) :

(a) 45 cm tube → 3 holes open → 2 sec gas insertion
(b) 45 cm tube → 3 holes open → 4 sec gas insertion
(c) 45 cm tube → 1 hole open → 2 sec gas insertion

6) Also, it was observed that people with different age-groups, sex etc. have significant difference in the CO_2 content of their exhaled air. Not only that, as seen before, the CO_2 percentage also changes significantly with the occurrence of the diseases like asthma and COPD.

7) The above experimentation has led us to the conclusion that the people with higher age, with respiratory diseases have abnormal CO_2 concentration in their exhaled air. Not only that, the CO_2 concentrations for normal people could also be found out by measurement through the above explained technique.

X. Future Scope

There is a lot of future scope for the present project. This sensor can be installed in a spirometer and can be used for online CO_2 measurement in the exhaled along with the other parameters which can be obtained from the spirometer. Thus, the spirometer will become more useful for varied purposes. The microcontroller can even be used to measure the transit time automatically. This will help to give a more precise out-put. Also, more precise indication of the condition of asthma can be done, instead of just three distinguishing factors.

DOI: 01.IJRTET.9.1.39

Int. J. on Recent Trends in Engineering and Technology, Vol. 9, No. 1, July 2013

More minute values of CO_2 concentration can be obtained. Thus, it can become a useful equipment for emergencies and for use in hospitals and the ICU's.

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